Interactive Multisensor Analysis Training

Wallace H. Wulfeck II
Space and Naval Warfare Systems Center, Code 2302
53560 Hull St. Bldg 586
San Diego, CA 92152 USA

Sandra K. Wetzel-Smith
Space and Naval Warfare Systems Center, Code 2302
53560 Hull St. Bldg 586
San Diego, CA 92152 USA

Janet L. Dickieson
Office of Naval Research
Code 34 CM FNC
800 N. Quincy St.
Arlington, VA 22217 USA

Summary:

The Interactive Multisensor Analysis Training (IMAT) project is aimed at improving the preparation of operational users of undersea-warfare sensor systems. The effort has focused on training at all levels from initial individual training ashore through team, platform, and collective training at-sea, at all skill levels from apprentice sensor operators to senior tactical commanders. Operators and tacticians at all levels need a deep and scientifically accurate, but not necessarily formal, understanding of the physical principles that underlie tactical employment of their sensors. IMAT systems use model-based scientific visualizations, including three-dimensional graphics and animations, to illustrate complex physical interactions in mission-relevant contexts, and to provide interactive virtual laboratories in which the principles can be explored. Concepts in instruction include radiated acoustic characteristics, propagation in range-dependent environments, and sensor properties. Training systems provide exploratory environments in which operators and tacticians can examine the effects of change in any of the variables involved in the end-to-end sequence of emission, transmission, reflection and detection. Sensor settings, environmental conditions, and target characteristics can all be modified through a "what-if" simulation approach. These technologies have been applied effectively in basic and advanced sensor operations/employment courses; in individual and team training simulators, and in on-board training. At the battle-group and theater level, new-technology systems are used for decision support during at-sea exercises and operations, and for post-event reconstruction and performance analysis. This paper describes the IMAT training philosophy and approach, the design of training systems, and training effectiveness.

Introduction

The Interactive Multisensor Analysis Training (IMAT) program is a major visualization effort in the US Navy conducted over the past nine years. The objective in this program is to provide performance support and training systems for extremely difficult cognitive tasks involved in Anti-Submarine Warfare (ASW). The effort has focused on training at all levels from initial training ashore through team, platform, and collective training at-sea, at all skill levels from apprentice sensor operators to senior tactical commanders.

ASW involves the use of a variety of **sensor** systems to locate an opposing **threat** or target submarine in the ocean **environment**, often while avoiding counterdetection**.** In particular:

> ***Threat*** energy ***Sources*** refer to the acoustic, electromagnetic, or electro-optical emission and/or reflection properties associated with undersea objects. This includes the types and parameters of signals emitted by them, such as frequency and amplitude. It also includes the azimuthal or "aspect dependent" variability associated with signals in the case of "passive" systems, and/or the reflective properties and aspect dependencies in the case of "active" systems. A source that is sufficiently energetic to be remotely detectable constitutes a *vulnerability*.
>
> ***Environment*** refers to the transmissive properties of the media through which (acoustic or electromagnetic) energy is propagated. The environment affects the path which energy takes as it is

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reflected and refracted, and the amount of loss that occurs as a result of transmission through the environment. In the passive case, one-way paths and path loss are studied, while in the active case both outgoing and reflected transmission is involved. Environmental properties that affect transmission include the refractivity of the medium, ambient or other interfering noise in the environment that affects signal-to-noise ratio, directional properties of noise, ocean bottom or terrain absorption and contour, reverberation, and other factors. Path loss is also a function of frequency (and in the case of electromagnetic energy so is refraction).

The ***Sensor*** or energy ***Receiver*** and its associated signal ***Processor*** determine how received vulnerabilities, as affected by the environment, are sensed, manipulated and displayed for human operators, tacticians, and strategists. These systems also are controlled by their operators who are seeking to optimize processing so that highest sensitivity is achieved.

These individual topics cannot be understood in isolation from one another. For example, sensor optimization depends on knowledge of the threat vulnerabilities and the intervening environment. A fundamental training problem is that changes in any of the source, environment, or sensor variables interact with all the others. And, for multiplatform operations (those involving multiple ships and aircraft), these triangular interactions increase exponentially.

ASW is an incredibly complicated task: At all levels from individual sensor operator to senior commander, mission success depends on:

- Correctly anticipating the relative merits of position, speed, maneuver and sensor/weapon employment….
- For each platform in the battle force...
- Against the possible range of threat options…
- Within highly variable environmental conditions, …
- In a rapidly changing combat situation in which intelligent opponents try to avoid detection, confuse identification and gain tactical advantage...
- Where other missions, such as air strike or missile defense, may have equal or greater importance to battle force survival.

To cope with tasks of this complexity, operators and tacticians need a deep understanding of the principles underlying operation and employment of their sensors.

Cognitive Complexity

Complex tasks like those involved in ASW are known to be difficult to learn. Nearly 50 years ago, Piaget noted the difficulty of tasks that require coordinating more than one dimension of variation (Inhelder & Piaget, 1958). Over 30 years ago, the state of Massachusetts (and since then many other governments) found it necessary to impose a unit pricing law, because of the difficulty most people have in determining best value among differently sized and priced containers of the same product—a relatively straightforward two-dimensional task. Feltovich and his colleagues (e.g. Feltovich, Spiro, & Coulsen, 1991) have described some features of tasks and/or problems that make them difficult. We have added a few additional criteria in the list below:

- **Abstract** (versus concrete). Physical phenomena are invisible and the underlying cause and effect relationships cannot be observed. Examples include the propagation of sound, or the patterns of sensitivity of an acoustic sensor.

- **Multi-variate** (versus univariate): Multiple underlying causes can affect an outcome. For example, the refraction of sound in water results from sound-speed variation with depth, which in turn depends on variations among salinity, pressure, and temperature with depth.
- **Interactive** (versus separable or additive). Underlying causes may interact with each other, with outcomes dependent on the interaction of variables in addition to each variable acting separately.
- **Continuous** (versus discrete). The dimensions of variation are continuous For example, speed, pressure, and temperature are all continuous variables. Rather than merely memorizing discrete state changes, the learner must understand the effects of continuous change.
- **Non-linear** (versus linear). The relationship of outcome to an underlying dimension is not a simple straight-line function; rather relationships may be exponential, logarithmic, or even more complex. For example, energy loss in propagation often involves an inverse-square relationship.
- **Dynamic** (versus static). The process of variation itself is the subject of analysis, rather than end or intermediate states. A few frozen moments in time are not sufficient to characterize the underlying variation.
- **Simultaneous** (versus sequential). Outcomes vary continuously with changes in underlying variables, rather than as a succession of states.
- **Conditional** (versus universal). Relationships among variables and outcomes may depend on particular boundary conditions or other contextual events. There may be exceptions to general rules or they may apply only in certain circumstances and not in others.
- **Uncertain** (versus certain). Exact values on underlying variables may not be known precisely; instead they may be interpolations, estimates, or approximations.
- **Ambiguous** (versus unique). The same combination of circumstances may result in multiple outcomes, or the same outcome may be the result of different combinations of circumstances.

Antisubmarine Warfare tasks involve all of these attributes. For example, understanding probability of detection involves the interaction of the target's radiated signals (which vary in three spatial dimensions around the target by frequency by time); the intervening environment which may distort or differentially enhance or attenuate signals at particular frequencies; and detectability of signals by a particular shipboard sensor (with directional sensitivity which also varies in frequency and in three spatial dimensions). This problem is further complicated when such factors as radiated noise variation with target speed and depth, ownship motion effects on directional frequency response of sensors, relative motion between target and sensor, and multipath interactions are considered. There are multiple, continuous, interactive, nonlinear, highly-dynamic dimensions of variability, with uncertainty and ambiguity, throughout the ASW problem space.

Interactive Multisensor Analysis Training (IMAT)

IMAT is designed to make difficult scientific and technical concepts underlying sensor employment and tactical planning comprehensible to their operational users. Operators, tacticians and senior decision makers each need to acquire a deep and scientifically accurate, but not necessarily formal, understanding of the physical principles that underlie tactical sensor employment and planning. To meet this requirement, the IMAT program is

- developing training systems which integrate computer models of physical phenomena with scientific visualization technologies to demonstrate the interactive relationships of threat, environment, and sensor

for operator training, and interactions of multiple sensor systems for tactician training from individual platform to battlegroup to theater;

- developing training and performance support systems using modeling and visualization technologies; and
- integrating curricula to provide training on sensor employment and high-level tactical planning skills.

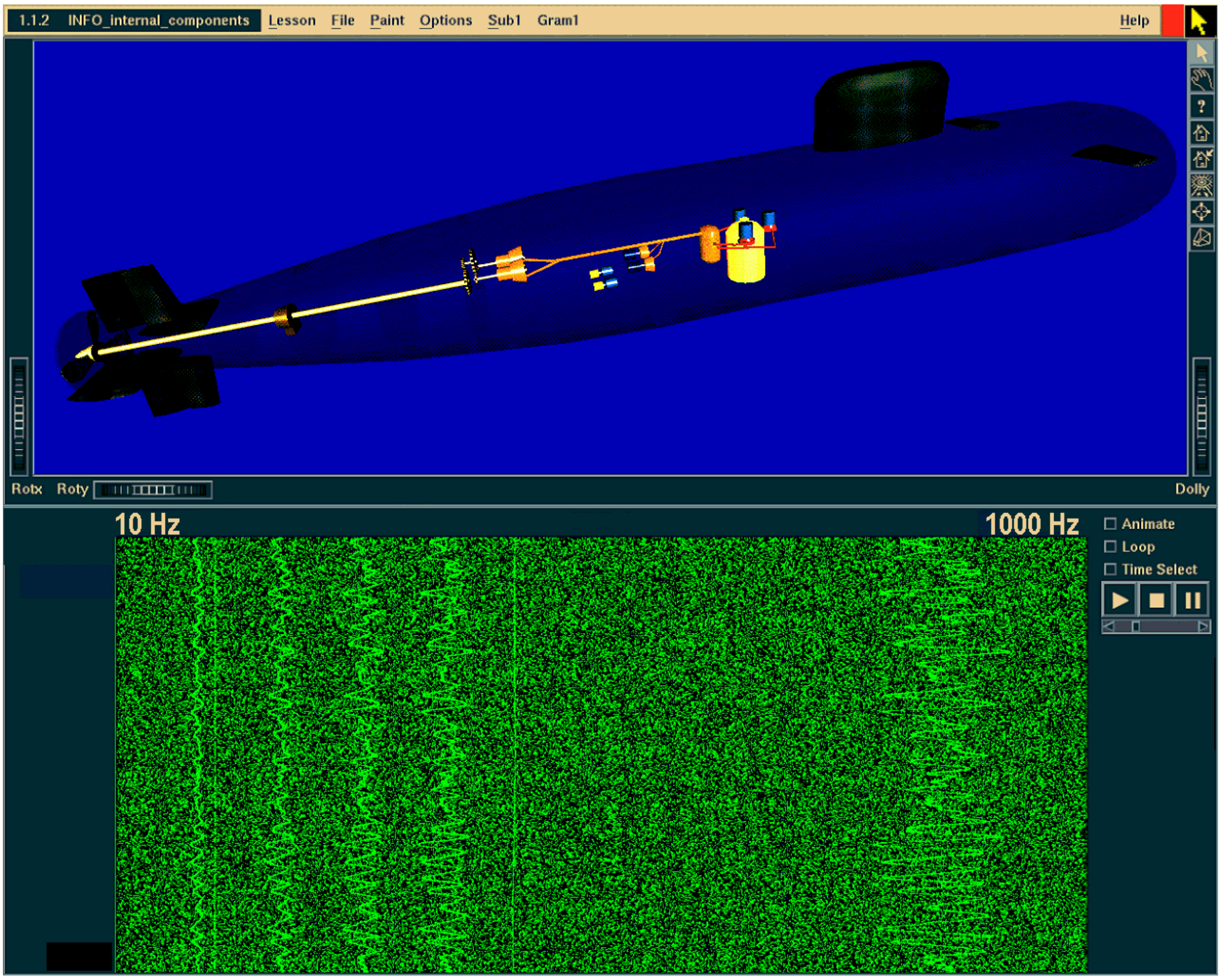
The most important design strategy in IMAT is to use computational physics models as the basic representation of task content. Models of physical phenomena and databases of environmental observations are integrated with scientific visualization technologies to build systems with which users can interact. These systems are used for analysis of cognitive requirements underlying successful task performance, in two ways. First, the physical relationships underlying sensor employment are explicitly identified, and second, task experts can interact with the systems to construct detailed representations of threat-sensor-environment variables and relationships. The visualizations can then be used in training episodes that demonstrate the interactive relationships among all the variables involved. Next, the modeling and visualizations are used during exercises and deployments to identify decision requirements, develop and refine user interfaces, and build tactical decision aids. These are iteratively refined in a build-test-build approach. Ultimately, systems are evolved which provide tactical decision aiding, while at the same time allowing drill-down inspection for tactical situation analysis, as well as exploration of variability in (a) assumptions about presumed target behavior and vulnerability; (b) own-sensor employment; and, (c) environmental effects on sensor effectiveness.

Model-based visualization:

Scientific Visualization is a critically important enabling technology for the design of modern mechanical systems, in medical imaging, and in most of the physical and engineering sciences. There are thousands of university and industrial projects in which visualization is employed to solve engineering, medical, or design projects. Most efforts are aimed at users with graduate degrees in a scientific field, and only a few involve training applications. A recent overview of information visualization is given by Card, Mackinlay and Shneiderman (1999). (Note: An annotated bibliography of Scientific Visualization web sites is located at http://www.nas.nasa.gov/Groups/VisTech/visWeblets.html).

IMAT uses extensive scientific visualization and takes advantage of work in a large number of university and US Navy research laboratories to develop models and databases. These include radiated noise models and databases which describe characteristics of sound sources; oceanographic models and databases which provide high-resolution bathymetric and bathythermographic information, ambient noise, bottom composition, meteorological and other physical effects on propagation; and sensor performance models including recent developments which take account of practical (but tactically relevant) effects such as array motion. In general, the approach has been to adopt these from their controlling organizations who are responsible for validation and verification. IMAT provides the visualization tools that allow the operational and tactical implications of interationships to become observable rather than invisible.

Sample IMAT visualizations are given in figures 1 through 3.



The Acoustic Source Display (Figure 1) is an example visualization of the internal components of a submarine. This is one view into a modeled acoustic laboratory for sound sources. The propulsion and auxiliary systems depicted in the diagram can all be animated to show how they operate, and the animations can be linked to recordings of acoustic data or to an audio simulation to show how acoustic parameters such as frequency are related to the physical operation. The user can select a motor, pump or other object in the diagram, which will highlight it and display a textual description of that object. Frequency lines associated with the component are highlighted on the sound spectrogram in the bottom part of the display. Each object is also linked to a more detailed three-dimensional representation that enables the student to gain a better understanding of how complex assemblies work, why they generate certain signals, and how signals relate to operating mode and speed. Modeled objects in the acoustic laboratory include examples of diesel engines, turbines, reduction gears, pumps, propellers, motors, generators, compressors, and blowers. Each object is also linked to a high fidelity acoustic simulator in which parameters that control the simulation can be varied and explored for instructional purposes. Motors, pumps, clutches, and other components can be activated and deactivated to show variations in operating mode; features such as number of cylinders, power cycles, or gear ratios can be changed; and depth and speed changes can be made, with all changes properly reflected in the visual and auditory displays.

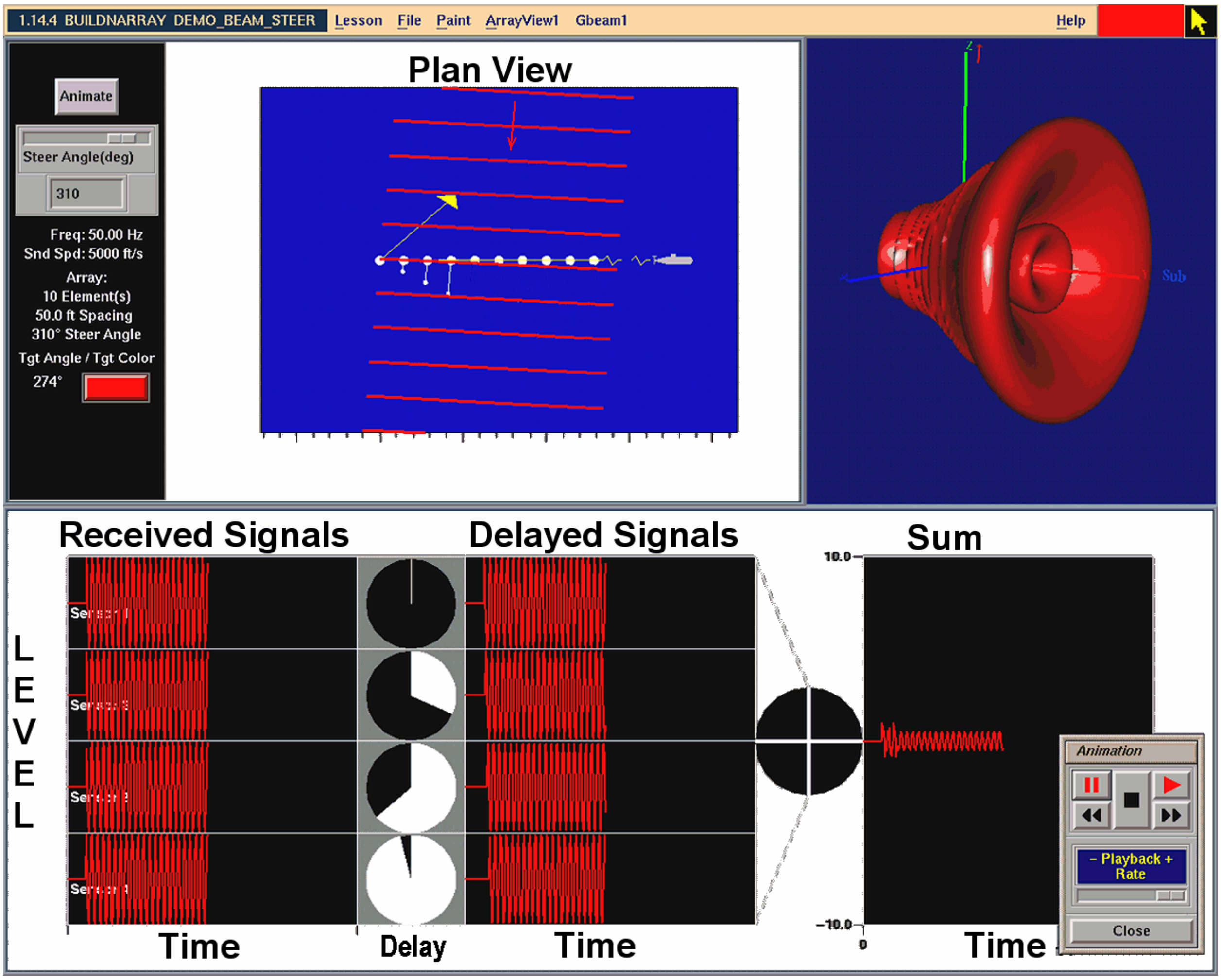


Figure 2 is a view of an interactive model-based animation for explaining the principles of phased array beamforming. Initially, basic concepts, such as element spacing related to frequency, and in-phase vs. out-of-phase arrival, are introduced using a simple two-element array. Later more complicated arrays of acoustic sensors are introduced. In Figure 2, the top right panel shows a 3-D rendered view of the 3dB-down isosensitivity surface for sound of a given frequency arriving at a notional 10-element line array. In the simulation, inter-element spacing and phase delays are all adjustable. The top-center panel shows delays applied to steer sensitivity for a particular frequency in the direction shown by the yellow arrow. "Ghost-elements" corresponding to signal delays are also shown. The bottom panel shows signals arriving at four of the elements, the amounts of delay on those elements, the resulting delayed signals (or the signals arriving at the ghost elements), and their sum. In this case, noise arriving from a direction other than the steer angle is added out of phase and effectively nulled. This interactive simulation is also capable of modeling multi-aperture and other array geometries. The student or instructor can change any of the parameters in these displays, in order to investigate beam width and directivity as a function of array design and employment.

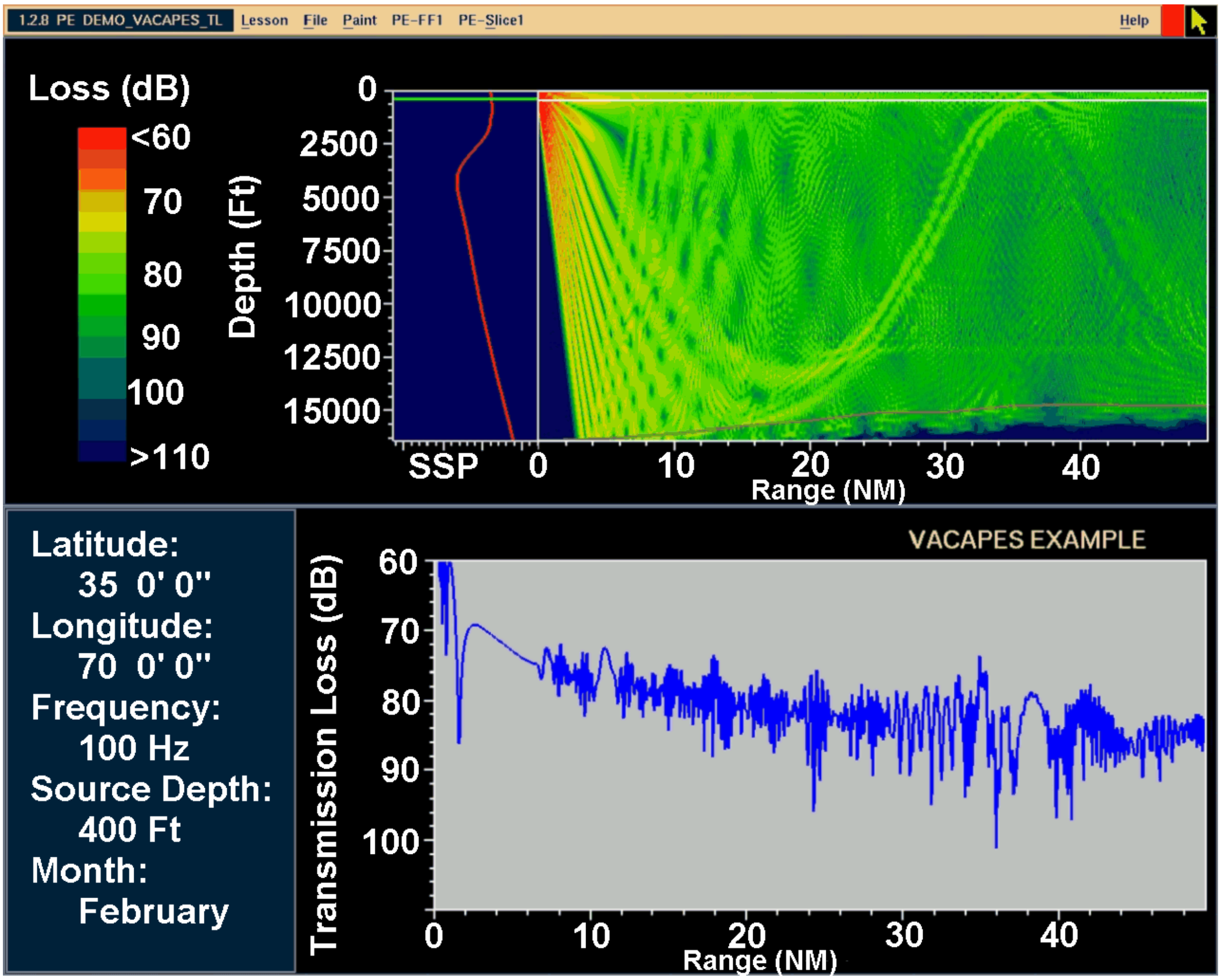


Figure 3 shows a view from the interactive modeling facility for transmission loss in the ocean environment. This allows a visual exploration of sound propagation paths due to reflection and refraction. A sound speed profile (SSP) is displayed on the left of the display. The bottom type, SSP, and bottom contour data can be manually entered or extracted from high-resolution databases. The top right panel shows an example full-field plot of energy loss, with the bottom panel showing transmission loss over range at the sensor depth indicated by the white horizontal line in the top panel. The user can simply drag the depth line to update the transmission loss plot. All the factors that affect transmission loss, such as spreading, absorption by the bottom, and scattering at the bottom and surface, are modeled and contribute to the interactive displays. IMAT includes extensive range-dependent propagation loss models, and databases of environmental data (such as sound speed or bottom absorption) approved by the Oceanographer of the Navy. With these modules, a user can select any geographic location and time of year, extract, view, enter, and/or modify environmental data, specify source and target depths and frequency of interest, and then investigate propagation loss as a function of depth, distance and azimuth from either a sensor or threat.

Task Analysis and development of Training Objectives:

The model-based scientific visualizations in IMAT have also enabled a new approach to the specification of training objectives. The analysis of complex conceptual tasks for training and educational purposes has been a central problem in instructional psychology for at least the past 50 years. The traditional method for analyzing a task, as described in most military training development guidance documents (e.g. NAVEDTRA 130 series in the US Navy), is to identify the components of a task by hierarchically decomposing it into subtasks, skills, and knowledge. Training is then based on these units, and they are tested mostly individually. This unfortunately results in a focus on low-level detail in training, so that students are presented materials as independent topics taught in a serial fashion with limited cause-and-effect explanation as to how those topics interrelate. This approach often leads to instruction in which students read and listen to lengthy descriptions of complex phenomena and memorize large amounts of factual data without any contextual reference. These methods produce graduates who can answer specific factual questions based on memorized information and who can perform procedures but cannot apply that knowledge in operational situations. For example, before IMAT, acoustic operators received instruction about oceanography and the physics of sound as if they were independent of a target submarine's operating environment, mission dependent acoustic characteristics, and the displayed frequency-based information resulting from sensor system engineering design. Operators trained with this approach could recite from memory specific threat emitter parameters, but did not necessarily know how to optimally employ a sensor system against that threat under specific environmental conditions. These operators could answer knowledge-based questions and perform procedures, but when confronted with a variety of real-world situations, they were not able to perform adequately. The operational problems that result include inefficient threat detection and ineffective environmental analysis.

These sorts of performance deficiencies are the result of the application of traditional analysis and instructional methods to these types of tasks. As Feltovich *et al* (1991) point out:

> "...common strategies of simplification...such as teaching topics in isolation from related ones (compartmentalizing knowledge), presenting only clear instances (and not the many pertinent exceptions), and requiring only reproductive memory in assessment are often in conflict with the realities of advanced learning—where components of knowledge are fundamentally interrelated, where context-dependent exceptions pervade, and where the ability to respond flexibly to "messy" application situations is required."

Further, when task analysis results in the introductory instruction for complex interrelated tasks being taught as a series of isolated topics, there may be a detrimental effect on future learning:

> "We have found these discrepancies between introductory and advanced learning often result in situations where the groundwork set down in introductory learning actually *interferes* with successful advanced learning."

More modern conceptual analysis methods take a different approach; they focus on the interrelationships of concepts in a technical domain, and for instructional design purposes they attempt to analyze the thought processes of the performer during performance of a task. However, proponents of cognitive task analysis have not yet had much success at developing their methods so that they can be routinely applied in complex warfighting tasks, and in some cases this approach has led to overly narrow characterizations of Navy training requirements.

The IMAT project has led to a process for conducting conceptual analyses, which involves the following general steps:

a. Define the most complex performance problem for which a training solution is required

b. Identify and refine the variables, and dimensions along which they vary, necessary to model the problem.

c. Obtain or develop mathematical and/or qualitative-process models which relate these variables/dimensions and specify how they interact.

d. Design an interface and display system which facilitates understanding of the variables and their relationships

e. Identify problem scenarios (cases) using the resulting simulation.

f. Validate the problem scenarios by working through them with operators and tacticians.

In general, the process of constructing and validating model-based visualization systems identifies the underlying critical variables, their relationships, and their tactical implications. These then become the enabling concepts and tasks in the analysis. This analytic methodology has now been successfully applied for acoustic, electromagnetic, and electro-optical systems, including revealing employment-training requirements for developmental systems still in test and evaluation.

IMAT Training Techniques

The IMAT effort provided a unique opportunity to integrate and jointly evaluate several of the developing cognitive techniques, including cognitive modeling, situated learning, elaborated explanations, and graphical techniques to promote visualization. The IMAT effort has adopted and tested several modern approaches to complex skill instruction, including the following:

a. *Contextualized/Anchored/Situated Instruction:* Task or job oriented instruction has been found to be more effective in learning, retention, and performance than topic oriented instruction (Semb & Ellis, 1994; Johnson, 1951; Duffy and Jonassen, 1991; Shoemaker, 1960; Steinemann, Harrigan, & VanMatre, 1967; Cognition & Technology Group at Vanderbilt, 1990; Collins, Brown, & Newman, 1989). IMAT has employed this approach in basic and advanced sensor employment and mission planning courses. (Czech, C., Walker, D., Tarker, B., & Ellis J.A., 1998).

b. *Graphic Displays/Interfaces Illustrate Cause and Effect Relationships and Help Concretize Invisible Phenomena and Events:* Research on learning from text has shown that adding pictures or graphics aids learning and retention if they supplement the text in some meaningful way (Dwyer, 1972; Gropper, 1966; Royer & Cable, 1976). Levie and Lentz (1982) in a meta-analysis of illustrated text studies concluded that learning and retention is facilitated by illustrations, if the illustrations are directly related to the text. The IMAT effort has shown that delivering instruction via graphical interfaces to conceptual models has a great effect on subsequent performance, both for apprentice and advanced tactical planning tasks (Wetzel-Smith, S.K. & C. Czech. (1996).

c. *Elaborated Explanations of Complex Tasks and Phenomena*: Providing students with elaborated explanations, analogies, etc. about how and why systems, events, and phenomena are structured and function should facilitate learning and retention. Research on learning skills and learning from text has shown that elaborated explanations enhance the students' mental models and increase retention (Mayer, 1989; Konoske & Ellis, 1991; Smith & Goodman, 1982; Swezey, Perez & Allen, 1991). IMAT has shown the same effects with Navy warfighting tasks (Ellis, J.A. Tarker, B., Devlin, S.E. and Wetzel-Smith, S.K. 1997).

d. *Instructional Sequencing:* Mental model development is facilitated by teaching students to reason about events and phenomena that involve several interrelated variables. Earlier research on sequencing showed that with simplified or isolated tasks, different sequences of instructional events made little difference. However, recent research and theory suggests that for complex tasks, sequencing strategies may have significant effects, and these are being observed in IMAT courses (Czech, C., Walker, D., Tarker, B., & Ellis J.A., 1998).

In each of these areas, before IMAT, little experimental work had been done on the extent to which the findings are generalizable to instruction delivered using simulation- and graphical-interface-based training technologies. Furthermore, there are almost no larger efforts that integrate all these approaches into an overall strategy. IMAT has proven the notion that a combination of these approaches will offer a potent learning environment for promoting acquisition of the kinds of complex skills involved in sensor-system operation and tactical planning.

Conceptual Training during Exercise Planning / Execution / Reconstruction

In tactical employment training, tasks involving planning and mission execution for any particular operating environment require that a planner understands how best to optimize the mix of sensor capabilities to detect and prosecute the threat. At the platform level, planners will have to understand which systems and system settings to select to best detect and prosecute an attack while accurately estimating likelihood of counterdetection and potential vulnerability. The tactician will need to predict the environmental effects on each of the sensors to be able to effectively plan and execute the mission. Previously, the training available to tactical planners tended to familiarize them with available environmental products, but did little to teach them how to apply the information in tactical planning and mission execution. IMAT training now allows tacticians to practice this sort of planning and mission execution, and IMAT systems can be used for timely reconstruction of exercises.

Over the past several years, the IMAT approach to tactical training has been explored in connection with at-sea exercises. During an exercise, IMAT researchers work on board with operators and command personnel to provide additional training in tactical use of the ocean in the context of the ship's performance during each watch period. Results typically indicate important performance improvements in the ship's sonar operations. Moreover, these improvements are retained during subsequent readiness evaluations.

This sort of exercise-based training has been repeated with dozens of submarines and surface ships. . To support these exercises, IMAT researchers often spend many weeks developing mission analyses, including oceanographic workups, sensor performance predictions, and counterdetection assessments, as well as displays and visualizations to deliver the training. The development of deployable mission analysis and reconstruction training will require developing authoring and visualization tools which can support much more rapid scenario (re)construction and display. The experience gained in these efforts has led to further definition of the requirements for deployable mission analysis and reconstruction tools

For interactive mission analysis training, novel methods of curriculum design are needed. IMAT training involves extensive use of case- or situation-based analysis/reconstruction training usable in several types of training scenarios:

- Provide a conceptual overview which gives an integrated expert-model based approach to understanding the variables affecting sonar tactics.
- Run pre-built training episodes which contain teaching points / instructional strategies for developing tactical skill.
- Use analysis capabilities of IMAT visualization systems to explore and critique sonar tactical planning for at-sea exercises.
- Use analysis capabilities of the visualization systems during exercise execution to explore what-if options for ownship and target(s). Use analysis / reconstruct capabilities to match predicted conditions with actual, then modify plans / projections.
- Use analysis / reconstruct capabilities for post-exercise sensor / tactics training assessment to provide "lessons-learned" reinforcement.

Most recently, these techniques have been extended to the force level, wherein several ships and aircraft conduct joint ASW operations. These forces are under the command of a senior tactician who, with his staff, prepares coordinated plans for the ASW problem, then monitors the execution of the plans, and ultimately is responsible for reconstruction and feedback to the units and personnel involved. To support ASW at the force level, IMAT researchers have built visualization systems that can be networked among the platforms involved to support collaborative training and mission execution. The US Navy has established IMAT Fleet Training Teams that deliver training at-sea at the platform and force levels.

Evaluations of Training Effectiveness

Measures of Effectiveness for Visualization-based training systems involve several different criteria. Training and performance aiding systems must first capture the complexity of real-world operations. This is assessed through developmental test and sensitivity analyses for performance prediction systems and through continual build-test-build cycles conducted with operational users of the systems under development. (1) Performance prediction systems must properly implement validated physics models and approved databases of input parameters. (2) These systems must properly model all major physical phenomena known to affect sensor / platform performance in real-world operations. (3) Performance prediction and visualization systems must by usable by experienced operators and tacticians so as to provide support through major phases of their tactical tasks, including planning, search, and prosecution. They should add little additional complexity to operator and tactician tasks. IMAT systems are subject to these kinds of criteria—they have been independently tested, and adopted for use as fleet-approved tactical decision aids by the US and other Navies.

Training improvements are assessed through pretest-posttest and training-vs-control evaluations on tests requiring knowledge and skill application on scenario-based tactical reasoning problems. IMAT visualization-based training consistently result in additional operator / tactician knowledge and skill. Evaluations of training effectiveness in ASW schools indicate that IMAT is among the most successful training technologies ever introduced in the US Navy (Committee on Technology for Future Naval Forces, 1997):

- IMAT students outperform students in conventional instruction, and in many cases score higher than qualified fleet personnel with 3 to 10 years experience. Evaluations consistently show gains of two to three standard deviations on comprehension, reasoning, and problem solving tasks. Overall, the IMAT approach is much more effective than conventional lecture instruction, or new technologies such as interactive video or computer-based training.
- Instructors report that IMAT increases their ability to teach difficult topics, respond to student questions, and reinforce critical principles.
- IMAT students score higher on attitude scales measuring attention, relevance, confidence, and satisfaction than students in standard Navy classrooms or students in specially designed individualized computer based training.

Finally, improved training should result in observable improvements in operator and tactician performance during exercises and operations, for example in improvements in the quality and timeliness of tactical plans and decisions made during tactical execution. Measures include: (1) better utilization of platforms (e.g. less overlap in sensor coverage), (2) deeper user examination of alternative courses of action during planning and execution, (3) improved availability and processing of information necessary to support planning and execution monitoring (e.g. minimize time spent collecting information while maximize time available for information analysis).

Ultimately of course, improved training and performance support systems should result in measurable improvements in military capability. Measures should reveal (1) increased detection / engagement ranges, (2) increased search rates or area coverage, (3) more rapid localization and classification, (4) reduction in prosecution of false contacts, (5) reduction in counter-detection and counter-attack vulnerability, and (6) increased tactical control or advantage. All of these measures are highly dependent on the boundary conditions for tactical exercises and operations – they can vary widely depending on any or all of the variables (e.g., threat parameters, environmental conditions, sensor employment, target behavior and tactics, ambient noise, etc.) that normally complicate military operations. IMAT researchers and training-team instructors have provided decision-aiding systems and advanced training to individual ships and to commanders and command staffs for battle groups. Independent evaluations of battle-group performance reveal improvements in all these measures.

Conclusion

The IMAT program is providing training and performance support systems designed to make difficult scientific and technical concepts comprehensible to the operational users of advanced sensor systems. The program is (1) developing systems which integrate computer models of physical phenomena with scientific visualization technologies to demonstrate the interactive relationships of threat, environment, and sensor for operator training, and interactions of multiple sensor systems for tactician training; (2) developing training and performance support systems using modeling and visualization technologies; (3) integrating curricula to provide training on high-level sensor operation and tactical planning skills; and (4) developing modeling and visualization tools for use at sea both for training and as tactical decision aids.

The IMAT vision is to integrate training, operational preparation, tactical execution, and post-mission analysis into a seamless support system for developing and maintaining mission-related critical skills. In many ways, IMAT is a prototype for future human performance support systems that transcend traditional shore school and course structures to span career-long skill development from apprentice to master levels, across missions, platforms, and communities.

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